***Spatial characterization of long-term hydrological change in the Arkavathy watershed adjacent to Bangalore, India -- Response to Referee 2***

**Response to Referee 2**

Referee comments in black

Our (author) responses in blue

Overall this is a well written manuscript that attempted to describe trends and spatial differences in changes in hydrology in the Arkavathy watershed on the basis of changes in extracted tank water surface area from satellite images along with other attributes.

- We thank the referee for consideration of our manuscript and valuable advice in helping us clarify some of the key messages of the paper. The referee's feedback has been helpful in alerting us to pieces of writing that need to be improved, particularly in clarifying the broader perspective.

Although the methods were well described, the broader perspective of the analysis is not well presented. After all the study analyzed the tank's surface water dynamics for a very small area (the total area of the Arkavathy is not provided), so, what new information does the findings bring to the community compared to the known facts at regional to national scale for India?

- We will provide the watershed area (4,160 sq. km) in Study Site section. We will clarify the broader implications of our research in the manuscript by making the following argument:
- The Arkavathy contains features that are characteristic of the landscape throughout much of Southern India, and although the findings from our study cannot be directly applied to the region as a whole (given the spatial heterogeneity of the change), the lessons from the Arkavathy can provide clues to hydrologic functioning in the broader region. India faces an array of water scarcity challenges, many of which have been studied at the country scale (Devineni et al., 2013; Tiwari et al., 2009) or at the local field scale (Perrin et al., 2012, Van Meter et al. 2016). Other studies have modeled hydrology at the local scale (Glendenning and Vervoort, 2011) and regional scale (Gosain et al., 2006), but none of these studies describe patterns of surface hydrological change. What is missing from the hydrology literature is an historical analysis at spatial and temporal scales commensurate with the scales of the change. The absence of hydrological records is a primary reason for this gap in the literature (Batchelor et al., 2002; Glendenning et al., 2015), and new datasets are needed that indicate hydrological change at a scale that sufficiently captures the spatial heterogeneity. Such a spatial understanding is particularly pertinent to our study region where the hydrology is truly local, because upstream and downstream subcatchments have been isolated by the fragmentation of the river network (due to tanks and check dams) and the subsurface disconnection due to the vastly depleted groundwater table (as we will clarify in our manuscript, urban effluent can serve to maintain a connected river network directly downstream of urban areas). The heterogeneity of observed changes in the Arkavathy emphasizes one of the problems associated with viewing water trends only at regional or national levels - such large scale trends to not map directly to local scales, yet these are the scales at which people experience and must respond to change. Such local understanding is of great importance to water managers in southern India, as

considerable efforts are underway for river and tank rehabilitation in some areas, without a clear understanding of the mechanisms underlying the historical degradation and loss of water resources (Kumar et al., 2016; Srinivasan et al., 2014).

Given the size of the tanks studied, I would imagine the seasonal water area dynamics will have greater implications than the inter-annual dynamics. The manuscript did not discuss anything on the seasonality for these tanks, or how does that influence the trend?

- We agree that seasonal dynamics are interesting to understand in so far as they indicate the seasonal availability of surface water resources. However, we avoided a detailed description of these dynamics for several reasons. Firstly, since tanks are not widely utilized as a surface water resource throughout the Arkavathy Basin today, the importance of understanding these seasonal dynamics is not so great in the present context as in situations where those surface water stores are relied upon by communities. The importance of the tanks as studied in this paper is as indicators of long-term changes through space in the hydrological dynamics that produce the end of monsoon season storage. Secondly, for pragmatic reasons, it is challenging to study within-year variations other than in the dry season. For approximately 6 months of the year, extensive cloud cover obscures many of the tanks in Landsat images and active radar satellite imagery (which can effectively “see through” clouds) is too coarse to estimate water area in small tanks. We appreciate the referee comments and we will more carefully discuss dry-season dynamics in the manuscript.

The manuscript mentioned about differences in water quality, turbidity, vegetation in the water which are influential factors for changes in the reflectance. Even though the DN values were converted to reflectance, the manuscript used only one index (NDWI) to classify water surface area, while there were potentially many other methods or index (Senay et al., 2013) could be used to map water surface correctly, as no one index can cover it all.

- We agree that there is no one method for remote sensing classification of surface water. We selected a simple classification method that was consistent across all Landsat sensors (MSS, TM, ETM, OLI). Our method uses NDWI as an initial classification, and we then apply spectral unmixing using Red, Green, and NIR bands. Although more complex methods have been published, they may not result in a significant improvement in confidence in our model, which we believe is sufficient for our purposes.

While the analysis was performed for the time period between 1972 and 2010 the validation was done for 2014 results. To me validation needs to be done for the time for which the trend analysis is performed (few sample years both wet and dry between 1972 and 2010).

As the study area is so small Google earth might provide good data for validation. Have the authors looked into google earth images as a potential source of validation data?

- We thank the referee for this suggestion. Our ability to completely validate the model between 1972 and 2010 is limited by the availability of independent data-sources at higher spatial resolution for such a validation - specifically, the lack of accessible aerial data for the region and the lack of low-cloud commercial high-resolution satellite datasets prior to early 2000s. Since, however, there is no reason to anticipate that the classification relationships should be non-stationary, we consider the most compelling part of the reviewer's suggestion is to address both relatively wet and relatively dry years, which can be accomplished using a more contemporary dataset. In particular, the suggestion to use Digital Globe (DG) images via Google Earth is sensible, and allows us to use images from as early as 2004 (although we note that individual DG images cover only a portion of the whole Arkavathy, so that the earliest date of available imagery varies). Specifically, there are DG images which may be suitable for validation (being close to the end of the monsoon season and having a suitable Landsat image taken at a similar time) and covering portions of the watershed on the following dates : 7-Dec-2005, 30-Dec-2006, 30-Dec-2007, and 25-Feb-2009, 7-Feb-2004 On 11-Feb-2009, and 8-Feb-2010.

- We are working on the details of a validation approach based on manual delineation of tank water area from the DG imagery which will be included in the revised paper. The scale of the validation in terms of the minimal number of tanks required will be decided via power analysis as follows: We set the null hypotheses that the actual correlation between the area of classified tanks and the area of validation tanks is greater than the correlation for tanks classified in our initial (2014) analysis described in the manuscript (H0: $R^2 > 0.95$). The null hypothesis is therefore that the actual $R^2$ is less than 0.95. If the true $R^2$ is 0.9, we would need 30-50 tanks to achieve a power of 0.5-0.75 in this statistical test to reject the null hypothesis. We will attempt to reach this number in multiple years, noting the limited spatial scale of DG images and limited date range (2004 and later).

Page 10 line 5: claims that MK analysis confirms an increase in agricultural land use fraction is related to decrease in tank water storage. How? There is no evidence shown in the manuscript that suggests agricultural land use is increasing. This is vague to me.

- We are going to restructure this analysis, and will make sure to clarify a number of key points. Agriculture has not expanded so much as it has changed over the course of the study period, and the changes in the nature of agriculture could be the cause of drying in the norther part of the Arkavathy. Bangalore has urbanized rapidly over the study period, with its population increasing by a factor of 4. We will clarify these points in the revised manuscript. Furthermore, using recently developed land use maps from 1973, 1994, 2001, and 2013 of the northern Arkavathy watershed (the 3 northernmost subcatchments), we will explore a more detailed analysis of the relationship between land use and hydrological change and present any additional findings in the updated manuscript.

Page 10 line 11-12: statement connects with changes in land use and management practice with depleted subsurface stores without providing evidence.

- We will restructure this analysis as well. We will provide more context regarding changes in land use as well as management practices. Our discussion was intended as an initial attempt as understanding drivers of hydrological change. We will clarify that this analysis is exploratory, and we will also provide more details from other works that have been written already (Srinivasan et al., 2015; Lele et al., 2014).

Page 11 line 6-7: Target for classification is to identify water and not water cells, in that case how does incorporation of additional land cover will reduce the classification error?

- Because we are using spectral unmixing, the land class end-member affects the calculated water fraction in each cell. For this reason, having additional (and more precise land classes) could potentially improve classification. We will clarify this point further in the paper.

I think the method used in the manuscript is too simplistic, although producing time- series information of tank water surface area is valuable. I am not sure how much new information has been brought to the community by this study; therefore I am not convinced that HESS is the right journal for this article.

- We agree that the classification is fairly simple, but overcomes a variety of challenges related to the study, such as the need to incorporate imagery from four Landsat sensors (MSS, TM, ETM, OLI), spectral unmixing in all images, cloud and cloud shadow masking, and the temporal nature of water in tanks (and single image gap filling in SLF-off images). We also note that the classification serves its purpose based on the validation we showed in the manuscript. The overall objectives for the paper (and updated validation information) will be clarified in the updated manuscript, as we describe above and in the letter to the editor.

Senay, G.B., Velpuri, N.M., Henok, A., Pervez, M.S., Asante, K.O., Gatarwa, K., Asefa, T., & Jay, A. (2013). Establishing an operational waterhole monitoring system using satellite data and hydrologic modelling: Application in the pastoral regions of East Africa. Pastoralism: Research, Policy and Practice, 3, 20.